Conjugated organic materials for active layers in transistors: Assessment of the electrical stability properties

H. L. Gomes¹, P. Stallinga¹, and D. M. de Leeuw²

¹ Center of Electronics Optoelectronics and Telecommunications, Faro, Algarve, Portugal
² Philips Research, Eindhoven, The Netherlands

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Motivation “Plastic electronics”

CEOT, OptoEl, Univ. do Algarve

“Stress” in FETs
(Bias-induced threshold voltage shift)

Temperature and bias dependence

Conclusions
Electronics of the Future

“Ambient intelligence”
Example: Printable Electronics

Using existing technologies (offset, gravure and flexo printing) to produce electronic circuits

... only organic electronics!

Reinhard Baumann,
MAN Roland Druckmaschinen AG, Germany
<table>
<thead>
<tr>
<th>Molecular Structure</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="image" /></td>
<td>regio-regular poly thiophene</td>
</tr>
<tr>
<td><img src="image2" alt="image" /></td>
<td>Poly methyl thiophene</td>
</tr>
<tr>
<td><img src="image3" alt="image" /></td>
<td>Sexi thiophene T6</td>
</tr>
<tr>
<td><img src="image4" alt="image" /></td>
<td>Poly phenylene vinylene</td>
</tr>
<tr>
<td><img src="image5" alt="image" /></td>
<td>Terylene</td>
</tr>
<tr>
<td><img src="image6" alt="image" /></td>
<td>[6,6]-phenly-C61-Butyric acid methyl ester (PCBM)</td>
</tr>
</tbody>
</table>
Vacuum sublimed organic thin film (α-sexithiophene)

Thickness: 4-8 nm

Example of a Field Effect Transistor

Cross section schematic:

Top view:

$\mu \approx 10^{-2} \text{ cm}^2/\text{Vs}$

$V_g = -4 \text{ V}$

$V_g = -6 \text{ V}$

$V_g = -8 \text{ V}$

$W/L = 10,000 / 10$
Bias-induced threshold voltage shift

FET channel

\[ V_{DS} \quad V_{GS} \quad I_{DS} \]

\[ \text{SiO}_2 \]

\[ \text{Gate voltage (V)} \]

\[ \text{Drain current (A)} \]

\[ V_T \quad V_T' \]
Stress effects and other effects

Stress caused by traps. Traps manifest themselves also in

- non-linear transfer curves \( I_{ds} \approx V_g^{1+\gamma} \) A
- field-dependent mobility \( (V_g \text{ and } V_{ds}) \) A
- Meyer-Neldel observation (thermal activation of current) B
- Non-exponentially decaying currents (Kohlrausch, 19th century) A

Very similar to amorphous silicon C, D

B: Stallings and Gomes, Organic Electronics 2005
Stress effects and the dielectric properties

Different surface chemical treatments

Stress occurs, even when different dielectric and different surface treatments are used!
Materials suffering from stress effects

**Polythienyle vinylene (PTV)**

**Pentace**
M. Matters *et al.* (1997)

**α-sexithiophene**
W. A. Schoonveld *et al.* (1999)

**Poly(3-dodecylthiophene)**
S. Scheinert *et al.* (2002)

**Regioregular-polythiophene.**
A. Salleo

**Poly-9,9´dioctyl-fluorene-co-bithiophene**

**Fluorinated copper phthalocyanine**
Street (2003)
Electrical characteristics

\[-I_{DS} \frac{1}{1 + 0.81}(A^{0.55})\]

\[-V_{GS}(V)\]

Time

\[5 \times 10^4 \text{s}\]
“Stretched exponential” behavior

\[ \Delta V_{th}(t) = \Delta V_0 \left( 1 - \exp \left[ -\left( \frac{t}{\tau} \right)^\beta \right] \right) \]

(*) 320 K  
(o) 296 K  
(+) 290 K
What is the nature of the traps?

Existing traps?
Created by the electric field?
Created by temperature (phase transition)?

Efficiency of trapping seems to be 100% (any free charge is eventually trapped)
Temperature dependent current

\[ V_{DS} = -0.5 \text{ V} \]
\[ V_G = -10 \text{ V} \]
Gate bias dependence

- $V_g = -10 \text{ V}$
- $V_g = -9 \text{ V}$
- $V_g = -8 \text{ V}$
- $V_g = -7 \text{ V}$
- $V_g = -5 \text{ V}$
Detrapping experiments

Cool down to 180 K with $V_g = -10$ V (fully stressed)

Warm up to 340 K with $V_{DS} = 0$ V while measuring the hole-detrapping current.
Detrapping current TSC

Device current

\[ I = \frac{A \exp(-\psi)}{[1 + B \exp(-\psi)\psi^{-2}]^2} \]

\[ \psi = \frac{E_A}{kT}. \]

\[ E_A = 0.51 \text{ eV} \]
Detrapping current

Filling with $V_g = -10 \text{ V}$ (stressed)

Higher heating rate

No filling $V_g = 0 \text{ V}$
Sample dependence

Independent of the processing and handling
Common to sexithiophene based materials.

Technology sensitive region

Current (nA)

Sample A
Sample B

Temperature (K)
Phase transition in nano-FET?

\[ V_g = \]

- \( \bullet \): -12 V
- \( \square \): -10 V
- \( + \): -8 V
- \( \times \): -6 V

Meyer-Neldel

Phase transition
Different materials

![Graph showing Log\(_{10}\) current versus 1/Temperature x 1000 (K\(^{-1}\)) for different materials: P3HT/PCBM (x 3), α-T6 (x 2), P3HT, and DH4T (x 10\(^{-3}\)).]
Different materials

$\alpha T6$ strong stress at 220 K

Terylene: No stress at 220 K
Conclusions

A “phase transition” occurs at $T = 220$ K, inducing new traps in the sample.

These traps states can be filled with holes and they are responsible for the stress effects.

At RT a new process sets in, causing further trapping. This process strongly depends on the handling and production conditions.

Stress is reversible (pulsed mode)

Different materials suffer from stress differently (rigid molecules are less prone to stress)
Acknowledgements

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